



Aphid feeding by lady beetles: higher consumption at higher temperature

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Abstract Many animals are challenged to respond to rising temperature due to climate warming. In this respect, we performed a laboratory experiment to show the influence of rising temperature on the consumption of *Acyrtosiphon pisum* Harris (Hemiptera: Aphididae), a serious aphid pest, by three common lady beetle species (Coleoptera: Coccinellidae). We used climate chambers, representing current temperature and two forecasted warming scenarios of 3 °C and 5 °C. Larval *Adalia bipunctata* Linnaeus (Coleoptera: Coccinellidae) and *Coccinella septempunctata* Linnaeus (Coleoptera: Coccinellidae), and adult *A. bipunctata* and *Harmonia axyridis* Pallas (Coleoptera: Coccinellidae) consumed significantly more aphid biomass at rising temperature. Larvae and adults of all species tested consumed significantly more aphid biomass per body weight, and larval body weight gain of all species was significantly higher at rising temperature. The higher consumption of aphid biomass is likely due to a higher demand for energy of adults, and faster growth of larvae.

Keywords *Adalia bipunctata* · Climate warming · *Coccinella septempunctata* · Coccinellidae · *Harmonia axyridis* · Pest control

Introduction

Annual mean global temperature has increased by 0.78 °C since the beginning of the 20th century (Mosbrugger 2012). Even though warming will not occur everywhere on earth (Kosaka and Xie 2013), there will be regions with elevated temperature. Global temperature is expected to rise between 3 °C and 5 °C by 2100 (Kromp-Kolb et al. 2014). If global warming reaches 2 °C, its impact on ecosystems worldwide will increase rapidly. A further increase can lead to more and more ecosystems collapsing (Warren et al. 2011). Even though increase of temperature is not the only ecosystem harming consequence of climate change, it is one of the strongest (Walther et al. 2002; Parmesan 2006). The impacts on agricultural ecosystems are difficult to foresee, but agricultural management is expected to face many challenges in the future (Adams et al. 1998; Howden et al. 2007). Biological pest control could be one of these challenges. The European parliament has demanded more biological pest control to reduce the use of pesticides (Buzek and Malmström 2009). Extensive knowledge of pest organisms and control agents will be essential to establish and stabilize

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effective biological pest management, especially at changing environmental conditions. The present study, which covers scenarios with elevated temperatures, is designed for regions that are undergoing temperature increases, such as Central Europe. In Austria, an increase of more than 1 °C is forecasted for the first half of this century. The second half of this century will strongly depend on future anthropogenic activities (Kromp-Kolb et al. 2014). There is a long history of using lady beetles as biological control agents against aphids (Hodek et al. 2012). Being ectothermic, both Coccinellidae and aphids, and their interactions, are highly affected by temperature (Sentis et al. 2012; Zhang et al. 2015; Raak-van den Berg et al. 2017).

Adults and larvae of the two-spot lady beetle (*Adalia bipunctata* Linnaeus; Coleoptera: Coccinellidae), the seven-spot lady beetle (*Coccinella septempunctata* Linnaeus; Coleoptera: Coccinellidae) and the harlequin lady beetle (*Harmonia axyridis* Pallas; Coleoptera: Coccinellidae) were tested, feeding on the pea aphid *Acyrtosiphon pisum* Harris (Hemiptera: Aphididae). *Adalia bipunctata* and *C. septempunctata* rank among the most common lady beetle species in Europe. Both are native and have been commercially used for biological pest control for decades (Omkar 2005; Hodek and Michaud 2008). *Harmonia axyridis* has become very common in Europe, where it is not native (Roy et al. 2016). This alien species is originally native to China, Japan, Korea, Mongolia and Siberia (Orlova-Bienkowskaja et al. 2015). In the 1960s, *H. axyridis* was first used as a biological control agent (Katsoyannos et al. 1997). In the 1980s *H. axyridis* was used as a biological control agent in Ukraine, and was later used in the rest of Europe (Adriaens et al. 2008). At this point, *H. axyridis* began to establish in the wild, where it is since considered both a biological control agent and an invasive species potentially threatening native lady beetles, particularly *A. bipunctata* (Camacho-Cervantes et al. 2017; Brown and Roy 2018). In Central Europe, the species can achieve between two and three generations per year (Honek et al. 2018). These three species are important biological control agents, which may be the reason why they are among the five lady beetle species that were most studied between 1995 and 2004 (Sloggett 2005).

Acyrtosiphon pisum, used as a food item for lady beetles in the present study, inhabits legumes and

causes severe damage to the host plants (Lukasik et al. 2011). It is a common food for all three lady beetle species tested and has been used as food in several studies on *A. bipunctata* and *C. septempunctata* (Blackman 1967; Kalushkov and Hodek 2004), and *H. axyridis* (Specty et al. 2003; Labrie et al. 2006).

Some studies have already been conducted on consumption of Coccinellidae related to temperature. Katsarou et al. (2005) tested larvae of *C. septempunctata* and *Hippodamia convergens* Guérin-Ménéville (Coleoptera: Coccinellidae) on *Myzus persicae* ssp. *nicotianae* Sulzer (Hemiptera: Aphididae) at 14 °C, 17 °C, 20 °C and 23 °C. Manrique et al. (2012) tested larvae of *Phaenochilus kashaya* Giorgi and Vandenberg (Coleoptera: Coccinellidae) fed on *Aulacaspis yasumatsui* Takagi (Hemiptera: Diaspididae) at temperatures of 20 °C, 25 °C and 30 °C. Sengenca et al. (2005) tested larval and adult *Serangium parcesetosum* Sicard (Coleoptera: Coccinellidae) fed on *Bemisia tabaci* Gennadius (Hemiptera: Aleyrodidae) at 18 °C and 30 °C, and Yu et al. (2013) tested larval and adult *Harmonia dimidiata* Fabricius (Coleoptera: Coccinellidae) fed on *Aphis gossypii* Glover (Hemiptera: Aphididae) at 15 °C, 20 °C and 25 °C. Overall, studies testing the effect of realistic climate warming scenarios on predator-pest interactions are rare (Frank and Bramböck 2016). Thus, while it is well documented (and not surprising) that aphid feeding by lady beetles is affected by temperature when tested over a large range, the present study investigates whether this also applies to a forecasted warming scenario within a small temperature range of 5 °C. In the present study, we investigated adults and larvae of the lady beetle species *A. bipunctata*, *C. septempunctata* and *H. axyridis*, as they are being particularly abundant in Central European open cultural landscapes. These three species were investigated under laboratory conditions at climate warming scenarios of 3 °C and 5 °C, forecasted for Central Europe. In combination with variation in day and night temperature, to our knowledge this has not been studied so far. We hypothesized that (1) total consumption of aphid biomass by adult and larval *A. bipunctata*, *C. septempunctata* and *H. axyridis* would increase with rising temperature, (2) adult and larval *A. bipunctata*, *C. septempunctata* and *H. axyridis* would consume more aphid biomass per body weight at rising temperature, and (3) larval *A. bipunctata*, *C. septempunctata* and *H.*

axyridis would gain more body weight at rising temperature. The focus of the present work is to gain insight into the potential of larvae and adults of common lady beetles to feed upon a common aphid pest relative to forecasted climate warming scenarios.

Materials and methods

Experimental conditions

The experiment was carried out in 2014 at the University of Natural Resources and Life Sciences Vienna, in the month of May, a period where larval and adult lady beetles are naturally active and feed upon aphids in the field. It was conducted in three climate chambers, each with a different temperature regime. Every chamber simulated a nearly constant day temperature between 6h00 and 18h00 and a nearly constant night temperature between 20h00 and 4h00, with increasing temperatures between 4h00 and 6h00 and decreasing temperatures between 18h00 and 20h00. The first climate chamber (T1) was adjusted to 19.3 °C during the day (measured at 12h00), 10.1 °C at night (measured at 0h00) and a 24 h mean temperature of 15.5 °C. T1 served as the basis temperature representing the mean temperature in Vienna, Austria in May (ZAMG 2016). The second chamber (T2) was set about 3 °C higher (day: 22.5 °C, night: 12.7 °C, 24 h mean: 18.6 °C), and the third (T3) about 5 °C higher (day: 24.4 °C, night: 14.4 °C, 24 h mean: 20.5 °C). For an overview of the three temperature regimes, see Fig. 1. Temperature was measured with Tiny-tag data loggers (Gemini Data Loggers Ltd,

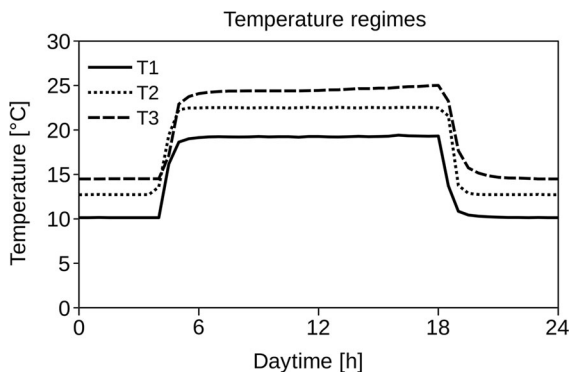


Fig. 1 Measured 24 h temperature curves of the temperature regimes T1, T2 and T3

Scientific House Terminus Road Chichester, West Sussex PO19 8UJ, UK). We used three identical data loggers to calibrate the climate chambers. To reduce measuring inaccuracy, we alternated the data loggers while calibrating the climate chambers. The applied warming scenarios of 3 °C and 5 °C are in the range of climate models for eastern Austria which compare the period 1961–1990 with 2017–2100 (Formayer et al. 2007). A 14:10 L:D photoperiod was used in the three chambers, reflecting mean light conditions in May. As larval lady beetle's rate of weight gain depends on the length of the photoperiod and is greater under longer photoperiods, e.g. *H. axyridis* (Reznik et al. 2015), we only considered the photoperiod that was representative of May.

The lady beetles were randomly placed in Petri dishes (inside diameter: 86 mm, inside height: 13 mm) placed on a wire frame inside the climate chambers. The body weights of the lady beetles and the aphids were measured with a laboratory scale Mettler AK 160. The aphids (*A. pisum*), used to feed the tested coccinellid species during the experiment were reared on pea plants after buying a start package from Terra Erfordia (Blumenstrasse 70/Haus 2, 99092 Erfurt, Germany). *Adalia bipunctata* was supplied by Prime Factory GmbH & Co. KG (Itzehoer Straße 10, 25581 Hennstedt, Germany) as eggs and larvae in the first instar. One part was reared to the second instar for the larval testing and the other part was reared to adults for the experiment. *Coccinella septempunctata* and *H. axyridis* of different colour morphs were collected as adults at Tulln district in Lower Austria (coordinates: N: 48°15.5' E: 015°50'). One part was used directly for the experiment and the other part of these adults was used for rearing larvae. Rearing always took place at room temperature. For all three species, larvae of the third and fourth instar were used for experiments.

Experiments

After separation of test lady beetles in Petri dishes, they were weighed and spread equally to the temperature levels T1, T2 and T3, assuring that the weights of lady beetles tested did not differ significantly between temperature regimes. Ten replicates per temperature regime were used, totalling 30 Petri dishes per experiment. After a starvation phase of 24 h for larvae and 48 h for adults at room temperature, the beetle's

body weight was measured again to obtain the start body weight for the experiment, described as “body weight before feeding” (Table 1, Fig. 2). Then every beetle was relocated into a new Petri dish together with weighed aphids on a bean stem. The experiment in the climate chambers was started after this step and lasted for 72 h. Every day, the Petri dishes were checked and refilled with weighed aphids to ensure ad libitum food availability, and aphids were provided with fresh bean stems. After 72 h, the weight of the remaining aphids was measured, i.e. live aphids plus carcasses of killed but not wholly consumed aphids. The “total consumption” was calculated as the difference between the provided aphid biomass and the remaining aphid biomass (dead and alive) after the experimental time. The beetles were relocated to new Petri dishes and passed a second starvation phase (larvae: 24 h, adults: 48 h), after which the body weight was measured again, described as “body weight after feeding” (Table 1, Fig. 2).

Statistical analysis

Tested with the Shapiro–Wilk test, total consumption, consumption per body weight, body weight before feeding, body weight after feeding, and body weight change of larval and adult lady beetles were normally distributed. Consumption per body weight is calculated as total consumption divided by body weight before feeding. Consumption per body weight was created to lower the influence of the body weight of tested lady beetles. This influence was tested by linear regressions between body weight and total consumption. Homogeneity of variances was tested with Levene’s test and was always fulfilled. One-way ANOVA followed by the Tukey post-hoc test for multiple comparisons was performed to test for differences in total consumption, consumption per body weight, body weight before feeding, body weight after feeding, and body weight change of larval and adult lady beetles between the three temperatures. All statistical analyses were performed with R version 3.0.2 (R Core Team 2013).

Results

Total consumption of aphids by larval *A. bipunctata* and *C. septempunctata* and adult *A. bipunctata* and

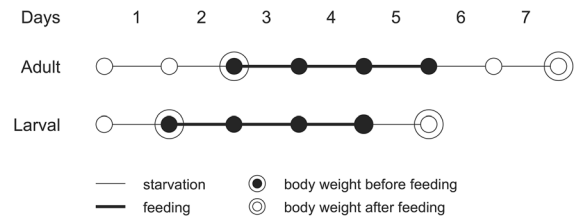


Fig. 2 Schema of the experimental design for adults and larvae

H. axyridis was significantly affected by temperature (Table 1). Larval *A. bipunctata* consumed significantly more aphid biomass at T3 than at T1 and T2 ($P = 0.001$; Tukey). Adult *A. bipunctata* fed on significantly more aphid biomass at T2 and T3 compared with T1 ($P < 0.001$). Larvae of *C. septempunctata* consumed significantly more aphid biomass at T3 than at T1 ($P = 0.001$), but feeding of adults remained unaffected by temperature. Whereas total aphid consumption by larval *H. axyridis* was not affected by temperature, adult *H. axyridis* fed significantly more at T3 than at T1 and T2 ($P = 0.002$ and $P = 0.040$, respectively).

Total consumption was significantly correlated with body weight for larvae (Fig. 3) and adults (Fig. 4) of all three species at all temperature levels, except for *A. bipunctata* larvae at T2 and T3. Consumption per body weight was significantly affected by temperature for larvae (Fig. 5) and adults (Fig. 6) of all three species. Larval *A. bipunctata* consumed significantly more aphid biomass per body weight at T3 compared with T1 and T2 ($P = 0.001$; Tukey). Adult *A. bipunctata* fed on more aphids per body weight at T2 than at T1 ($P < 0.001$) and consumed more at T3 than at T2 ($P < 0.001$). Larval *C. septempunctata* consumed significantly more aphid biomass at T3 compared with T1 ($P < 0.001$) and T2 ($P = 0.001$), and at T2 compared with T1 ($P = 0.016$). Adult *C. septempunctata* fed on more aphid biomass per body weight at T3 than at T1 ($P = 0.023$). Larval *H. axyridis* consumed significantly more aphid biomass per body weight at T3 compared with T1 ($P < 0.001$) and T2 ($P = 0.002$), and at T2 compared with T1 ($P = 0.003$). Adults of *H. axyridis* consumed more aphid biomass per body weight at T2 and T3 compared with T1 ($P = 0.031$ and $P < 0.001$, respectively).

The larvae of all three species showed significantly different body weight changes at each temperature level, i.e. the difference of body weight before feeding

Table 1 ANOVA results (means and SE) of aphid biomass consumption, body weight before and after feeding, and body weight change for *A. bipunctata*, *C. septempunctata* and *H. axyridis* at the temperature regimes T1, T2 and T3

Temperature	T1	T2	T3	One-way ANOVA	
	Mean \pm SE	Mean \pm SE	Mean \pm SE	F	P
<i>Adalia bipunctata</i> (larval)					
Consumption (mg)	25.7 \pm 3.1a	26.4 \pm 2.6a	45.2 \pm 4.0b	11.12	< 0.001
Body weight before feeding (mg)	3.4 \pm 0.4	3.3 \pm 0.3	3.4 \pm 0.3	0.04	0.960 ns
Body weight after feeding (mg)	7.0 \pm 0.7	7.6 \pm 0.9	9.4 \pm 1.1	1.9	0.170 ns
Body weight change (%)	106.4 \pm 11.9a	129.2 \pm 18.1ab	175.1 \pm 23.2b	3.64	0.040
<i>Adalia bipunctata</i> (adult)					
Consumption (mg)	49.0 \pm 3.2a	72.3 \pm 2.8b	82.3 \pm 4.3b	23.73	< 0.001
Body weight before feeding (mg)	9.9 \pm 0.4	10.4 \pm 0.3	9.6 \pm 0.6	0.78	0.468 ns
Body weight after feeding (mg)	10.2 \pm 0.5	11.2 \pm 0.6	10.4 \pm 0.7	0.82	0.449 ns
Body weight change (%)	3.0 \pm 0.9	7.0 \pm 2.5	8.4 \pm 1.4	2.475	0.103 ns
<i>Coccinella septempunctata</i> (larval)					
Consumption (mg)	50.0 \pm 3.5a	66.5 \pm 6.6ab	87.2 \pm 7.8b	8.9	0.001
Body weight before feeding (mg)	5.7 \pm 0.4	5.8 \pm 0.4	5.9 \pm 0.4	0.04	0.959 ns
Body weight after feeding (mg)	11.6 \pm 1.2	15.0 \pm 2.1	16.6 \pm 1.9	2.05	0.149 ns
Body weight change (%)	99.9 \pm 11.2a	149.8 \pm 21.8b	174.8 \pm 20.2c	4.33	0.023
<i>Coccinella septempunctata</i> (adult)					
Consumption (mg)	71.2 \pm 10.1	81.4 \pm 10.9	90.0 \pm 10.8	0.466	0.466 ns
Body weight before feeding (mg)	30.8 \pm 5.3	30.9 \pm 4.2	26.6 \pm 4.0	0.29	0.751 ns
Body weight after feeding (mg)	30.9 \pm 5.8	31.2 \pm 4.5	27.3 \pm 4.2	0.2	0.821 ns
Body weight change (%)	- 2.0 \pm 1.7	- 0.3 \pm 2.2	1.7 \pm 3.0	0.596	0.558 ns
<i>Harmonia axyridis</i> (larval)					
Consumption (mg)	52.5 \pm 4.2	66.1 \pm 6.1	73.4 \pm 7.7	2.97	0.068 ns
Body weight before feeding (mg)	8.7 \pm 0.7	8.4 \pm 0.6	7.7 \pm 0.8	0.52	0.603 ns
Body weight after feeding (mg)	17.9 \pm 1.7	21.9 \pm 2.5	21.9 \pm 2.8	0.9	0.418 ns
Body weight change (%)	103.0 \pm 6.7a	152.2 \pm 15.0b	178.0 \pm 14.4c	9.11	0.001
<i>Harmonia axyridis</i> (adult)					
Consumption (mg)	88.2 \pm 6.8a	101.9 \pm 7.3	130.5 \pm 9.1	7.62	0.002
Body weight before feeding (mg)	26.3 \pm 1.8	25.2 \pm 2.1	27.2 \pm 2.0	0.25	0.779 ns
Body weight after feeding (mg)	26.4 \pm 1.9	26.7 \pm 2.5	28.3 \pm 2.2	0.21	0.813 ns
Body weight change (%)	0.3 \pm 1.4	5.3 \pm 2.6	4.1 \pm 2.6	1.326	0.282 ns

All F values reported are on 2 and 27 df. Different letters next to the results denote significant differences between temperatures (Tukey, $P < 0.05$), ns: non-significant

and body weight after feeding over 72 h ($P < 0.001$ for each species). The body weight of the larvae was significantly affected by higher temperatures (Table 1). Larvae of both *A. bipunctata* and *C. septempunctata* showed a significant difference between T1 and T3 ($P = 0.035$ and $P = 0.020$, respectively). *Harmonia axyridis* larvae showed a significant difference between T1 and T3 ($P = 0.001$) and between T1 and T2 ($P = 0.027$). In

contrast, body weight change of adults was never affected by rising temperature.

Discussion

Total consumption of aphid biomass by adult and larval *A. bipunctata*, *C. septempunctata* and *H. axyridis* increased significantly with rising temperature in four of six cases, which partially confirms hypothesis

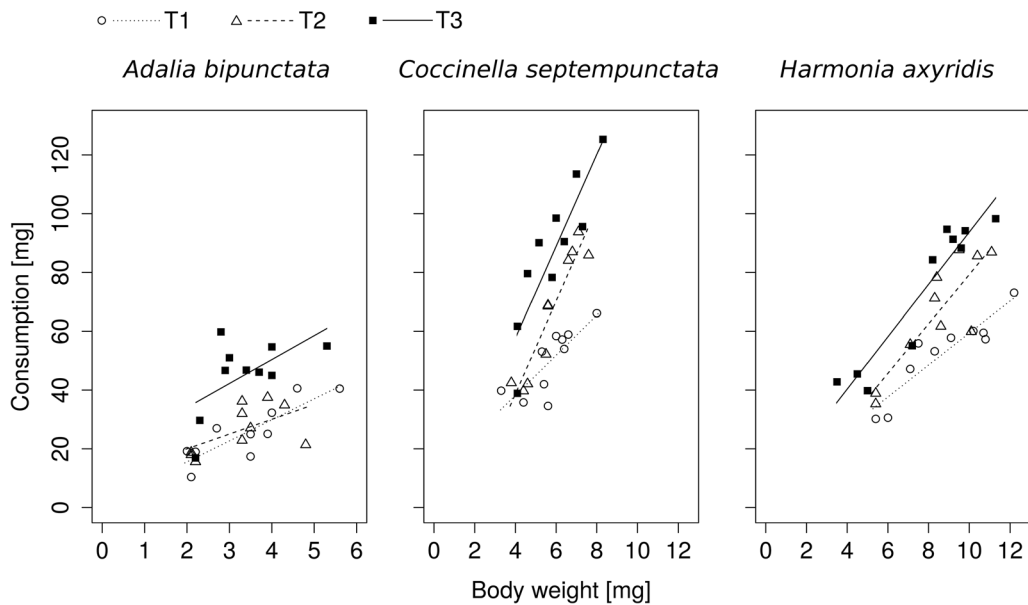


Fig. 3 Relationship between lady beetle body weight and aphid consumption for larvae (*A. bipunctata* T1: $y = 1.261 + 7.152x$, $r^2 = 0.728$, $P = 0.002$, T2: $y = 9.952 + 5.027x$, $r^2 = 0.323$, $P = 0.087^*$, T3: $y = 17.841 + 8.134x$, $r^2 = 0.350$, $P = 0.072^*$, *C. septempunctata* T1: $y = 10.993 + 6.806x$, $r^2 = 0.625$, $P = 0.007$, T2: $y = -24.566 + 15.803x$, $r^2 = 0.892$, $P < 0.001$, T3: $y = -4.842 + 15.622x$, $r^2 = 0.790$,

$P = 0.001$, *H. axyridis* T1: $y = 5.083 + 5.430x$, $r^2 = 0.837$, $P < 0.001$, T2: $y = -4.653 + 8.393x$, $r^2 = 0.747$, $P = 0.001$, T3: $y = 4.701 + 8.903x$, $r^2 = 0.895$, $P < 0.001$) at the three temperatures T1, T2 and T3. “*”: Though non-significant relationship, trend line is plotted for better comparability with significant relationships. *A. bipunctata*: different scale of x-axis

1. Adult and larval *A. bipunctata*, *C. septempunctata* and *H. axyridis* always consumed significantly more aphid biomass per body weight at higher temperature, thus verifying hypothesis 2.

In accordance with our study, Soares et al. (2003) observed increasing aphid consumption by *H. axyridis* larvae and adults between 10 and 25 °C. In the present study, adult *H. axyridis* also consumed more aphid biomass at the highest temperature regime (T3) compared with the lowest (T1, Table 1), spanning a range of 5 °C. *Adalia bipunctata* adults and larvae also consumed more aphid biomass at higher temperature, but no comparable study is available for this lady beetle from the literature. In contrast to larval *C. septempunctata*, total consumption of aphid biomass by adult *C. septempunctata* was not affected by temperature. Adult *C. septempunctata* differed from *A. bipunctata* and *H. axyridis* not only in the lower differences between the mean values of aphid biomass consumption at different temperature regimes, the species also showed higher SD. This could be an explanation why total aphid consumption by adult *C. septempunctata* remained unaffected by

temperature. As expected in the case of adults, there was no change in body weight before and after feeding in adults of either species. Thus, the difference in adult consumption can be explained by a higher demand for energy due to higher metabolism activity caused by higher temperature (Brown et al. 2004). Larvae, on the other hand, grow over time and develop faster at higher temperatures. For example, *A. bipunctata* showed faster development up to 30 °C. Over 30 °C the development rate decreases (Jalali et al. 2009, 2010a, b), and *H. axyridis* larvae showed faster development with increasing temperature between 15 and 25 °C (Castro et al. 2011). Reduced development times at rising temperatures means that larvae at T3 should develop faster than those at T2, which in turn should develop faster than those at T1. Development time in turn should affect aphid consumption by larval lady beetles. In fact, Schüder et al. (2004) observed that *A. bipunctata* developed faster at rising temperature and consumed the same number of aphids in a shorter time period. All three species in the present study showed significantly higher body weight changes at rising temperature, which underpins this

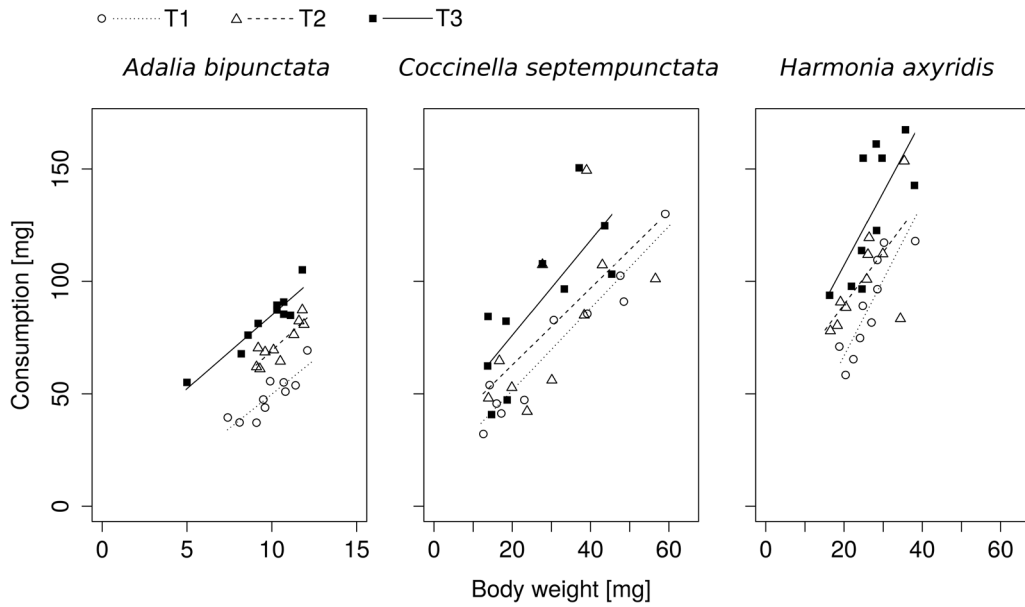


Fig. 4 Relationship between lady beetle body weight and aphid consumption for adults (*A. bipunctata* T1: $y = -10.924 + 6.080x$, $r^2 = 0.764$, $P = 0.001$, T2: $y = -0.623 + 6.984x$, $r^2 = 0.767$, $P = 0.001$, T3: $y = 19.623 + 6.538x$, $r^2 = 0.888$, $P < 0.001$, *C. septempunctata* T1: $y = 15.045 + 1.823x$, $r^2 = 0.925$, $P < 0.001$, T2: $y = 28.712 + 1.705x$, $r^2 = 0.433$,

$P = 0.039$, T3: $y = 33.862 + 2.107x$, $r^2 = 0.593$, $P = 0.009$, *H. axyridis* T1: $y = -0.840 + 3.385x$, $r^2 = 0.770$, $P = 0.001$, T2: $y = 42.159 + 2.327x$, $r^2 = 0.441$, $P = 0.036$, T3: $y = 42.296 + 3.243x$, $r^2 = 0.507$, $P = 0.021$) at the three temperatures T1, T2 and T3. *A. bipunctata*: different scale of x-axis

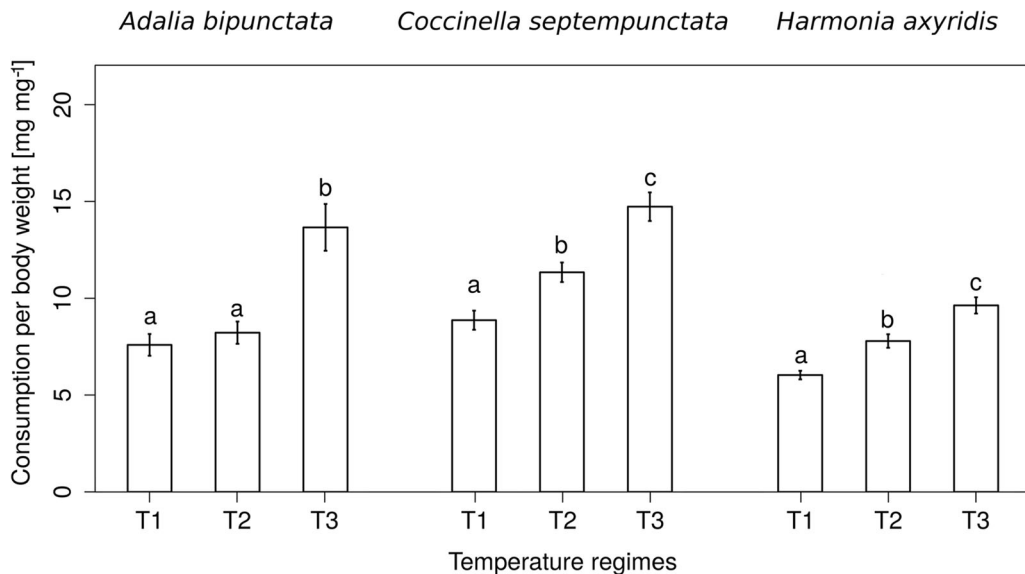


Fig. 5 Aphid biomass consumption per body weight for larvae (*A. bipunctata*, *C. septempunctata* and *H. axyridis*) at the three temperatures T1, T2 and T3. Bar charts reveal means and SE.

Different letters above bars stand for each species separately and denote significant differences between temperatures (Tukey, $P < 0.05$)

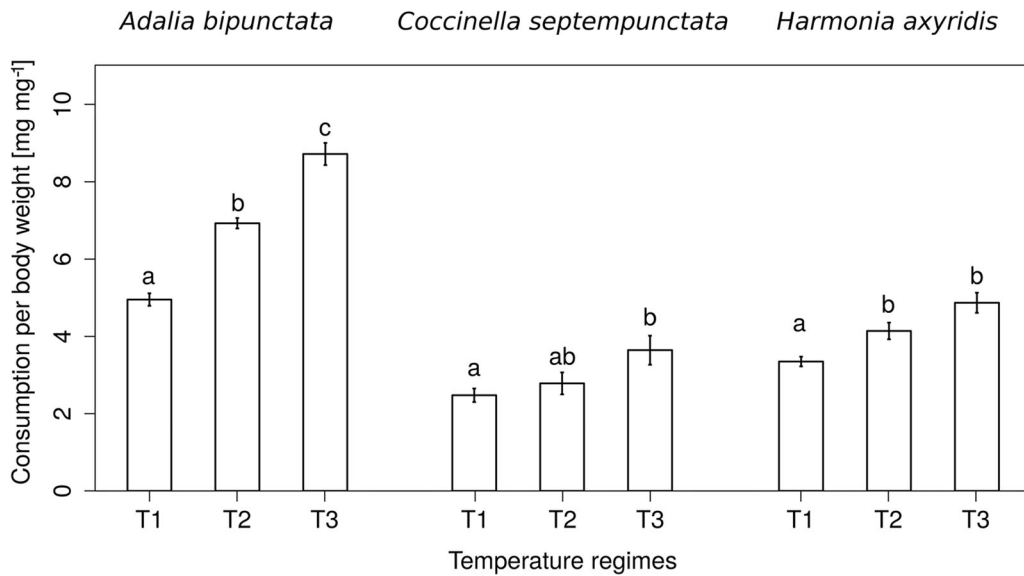


Fig. 6 Aphid biomass consumption per body weight for adults (*A. bipunctata*, *C. septempunctata* and *H. axyridis*) at the three temperatures T1, T2 and T3. Bar charts reveal means and SE.

argumentation and confirms hypothesis 3 (Table 1). Katsarou et al. (2005) showed increased mean daily consumption of the aphid *Myzus persicae* by larval *C. septempunctata* from 14 to 23 °C, which coincides with the results of the present study.

We expected that body weight would influence total consumption because of the dependence of metabolic rate on body mass (Brown et al. 2004). The regression analyses revealed the influence of body weight of the tested species on aphid consumption in 16 out of 18 tested relationships, and thus confirmed our expectation (Figs. 3, 4). To exclude the influence of body weight on consumption, we divided consumption by body weight. This led to lower SD and better separation between the data of temperatures T1–T3, which was demonstrated by clear significant differences between the temperatures for all six cases studied (Figs. 5, 6).

Higher temperature may not only lead to higher consumption by predators but can also affect development of prey. The aphid *A. pisum* has been observed to develop faster with rising temperature, i.e. its development increased from 10 to 26 °C (Bieri et al. 1983; Morgan et al. 2001). Moreover, Morgan et al. (2001) found that even the population growth of *A. pisum* increased with rising temperature between 12 and 23 °C. Thus, within a similar temperature range, both aphid development and lady beetle feeding

Different letters above bars stand for each species separately and denote significant differences between temperatures (Tukey, $P < 0.05$)

on aphids are increased. What the results of our laboratory experiment mean for field population development of *A. pisum* is not yet clear. This was also indicated for the aphid *Sitobion avenae* Fabricius (Hemiptera: Aphididae) by Skirvin et al. (1997), who modelled declining numbers of *S. avenae* at higher temperature regardless of whether the aphid predator *C. septempunctata* was present or not. Yet our lab results indicate a clear potential for increased feeding on aphids by lady beetles at rising temperature. The available literature on laboratory studies observing that lady beetles consume more at rising temperature addresses temperature ranges spanning about 10 °C or more (Sengonca et al. 2005; Manrique et al. 2012; Yu et al. 2013). In contrast, our study was performed over a range of only 3 °C and 5 °C. This span, which was created under laboratory conditions and included day-night oscillations, represents a forecasted global climate warming scenario.

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